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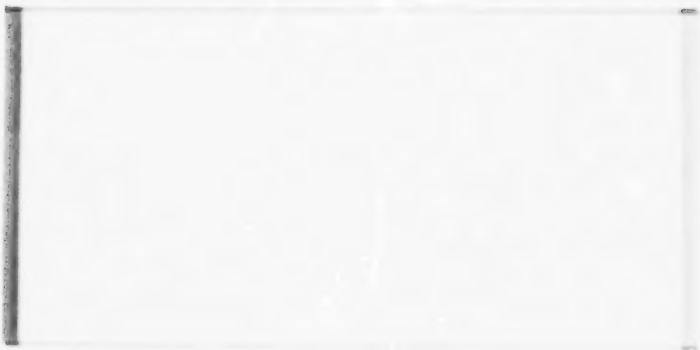

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DISPERSION MODELLING FOR NUCLEAR EMERGENCY RESPONSE

Report No 86-366-K

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ABSTRACT

The Continuous Release Dispersion Model, CRDM, has been incorporated into a new computer code called ERP (Emergency Response Planning). ERP was used in the recent nuclear emergency exercise held for Bruce NGS 'B'. It estimates source term, calculates atmospheric dispersion using CRDM and predicts radiation doses. CRDM is a surface similarity model which calculates atmospheric dilution factors for a near surface continuous release of non-reactive contaminants. This report includes a detailed description of CRDM plus a computer program listing. The report concludes with the following recommendations that (i) model validation be undertaken using newly available data; (ii) building wake effects be included in CRDM; (iii) the version of CRDM which calculates wet and dry deposition be incorporated into ERP; and (iv) a computerized meteorological data acquisition system be implemented.

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DISPERSION MODELLING FOR NUCLEAR EMERGENCY RESPONSE

1.0 INTRODUCTION

Nuclear emergency exercises based on simulated accidents at nuclear generating stations are regularly held by the Ontario Ministry of the Solicitor General in cooperation with Ontario Hydro. Such exercises test the Province of Ontario Nuclear Emergency Plan (1984). In the unlikely event of an accident, this Plan requires that the projections of off-site radiation dose patterns be made to allow timely decision-making on protective actions. An important part of any dose projection scheme is a means of predicting the transport and diffusion of emissions by atmospheric winds and turbulence. This report describes an atmospheric dispersion model developed for this purpose. The model is called CRDM (Continuous Release Dispersion Model) and it was originally written for use in a nuclear emergency exercise held for Pickering NGS in May of 1983 (Wright, 1983).

On September 19, 1985, another nuclear contingency exercise took place for Pickering NGS (Ogram and Wright, 1986). For this exercise, a computerized atmospheric dispersion modelling system called NEADM (Nuclear Emergency Atmospheric Dispersion and Dose Model) was developed and implemented (Ogram et al, 1985). NEADM was coded for use on an IBM-PC compatible microcomputer and was comprised of two components, CRDM and AQPUF. AQPUF was a puff model designed to treat short duration releases and was written by S. Daggupaty of Environment Canada. These models were interfaced with a simple dose conversion module based on the Draft Canadian Standard CSA N288.2 (Wright, 1985).

For the exercise held for Bruce NGS 'B' on November 13, 1986, CRDM was incorported into a new computer code, ERP (Emergency Response Planning). ERP was developed at Ontario Hydro (Morrison, 1986) to estimate the source term, calculate atmospheric dispersion and predict radiation doses.

2.0 ERP

The primary use of ERP under the Provincial Plan is to provide dose projections by estimating source term and atmospheric dilution factors. Important criteria to be met in developing ERP were:

(i) the program should run on commonly available microcomputers,

(ii) the program should have sufficiently rapid response time,

(iii) the program should use appropriate default data (station and meteorological data) requiring minimum user input,

(iv) the program should have reasonable input data requirements,

(v) the program should remove any unnecessary subjectivity on the part of the user, and

(vi) the program should be as accurate as possible.

To estimate source term, ERP uses the calculation routine FASTDOS. FASTDOS simulates the behaviour of fission products inside the containment of a reactor and calculates the release of these fission products from containment either by leakage or by the filtered air discharge system. The effects of radioactive decay, plateout, desorption and filtration are included. FASTDOS is based on a similar computer program called FISSCON II (Jamieson and Fluke, 1982) which runs on a mainframe computer.

CRDM is used as the atmospheric dispersion model in ERP. CRDM departs from the traditional Gaussian model by using an approach based on similarity theory to describe the vertical growth of the plume. It is described in detailed in the remainder of this report.

3.0 CRDM

The Continuous Release Dispersion Model, CRDM, is a surface similarity model which calculates dilution factors for a near surface continuous release of non-reactive contaminants. The surface similarity modelling technique is based on experimental evidence which shows that vertical diffusion within the atmospheric surface layer (the region of the atmosphere nearest the ground which is directly influenced by the presence of the surface (van Egmond and Kesseboom, 1982)) can be determined by a limited number of parameters (Businger, 1973). An approach based on similarity theory expresses mean meteorological variables such as u (wind speed) and K (eddy diffusivity), which control vertical diffusion, as universal functions of the well-defined scaling parameters; z_0 (surface routhness length); u_* (friction velocity); and L (Monin-Obukhov length). Therefore, similarity models can explicitly treat the known variation of u and K with height in the surface layer.

Assuming diffusion in the downwind direction is negligible compared to horizontal advection, vertical dispersion from a continuous stationary source is governed by

$$u(z)\ \frac{\partial C_y}{\partial x} = \frac{\partial}{\partial z}\ [K_z(z)\ \frac{\partial C_y}{\partial z}] \qquad (1)$$

where C_y is the crosswind integrated pollutant concentration (unit m^{-2}), $u(m\ s^{-1})$ is the horizontal wind speed and K_z ($m^2\ s^{-1}$) is the vertical eddy diffusivity. The coordinates x and z measure the distance downwind from the emitter and the distance above the ground, respectively.

Using the similarity profiles of Businger (1973), which express u and K_z as functions of z_0, u_* and L and solving the diffusion equation, the following formula can be derived (Van Ulden, 1978, Horst, 1979) for the dilution factor $\chi/Q(x,y,z)$ ($s\ m^{-3}$)

$$\chi/Q = \{0.73 \exp [(-0.66z/\bar{z})^{1.5}] \exp (-y^2/2\sigma_y^2)\}/(\sqrt{2\pi}\ \bar{u}\ \bar{z}\ \sigma_y) \qquad (2)$$

where horizontal diffusion is assumed to be Gaussian (a justified assumption because conditions are expected to be reasonably homogeneous in the horizontal) and

$\bar{u}$ is the mean horizontal wind speed of the plume ($m\ s^{-1}$)

$\bar{z}$ is the mean height of the plume material (m)

σ_y is the horizontal standard deviation (m).

3.1 ATMOSPHERIC STABILITY

The surface similarity modelling technique does not require the input of an atmospheric stability class, an empirical parameter which is often difficult to specify with confidence. Different methods of determining stability class often give quite different results (Miller and Little, 1980, Sedifan and Bennet, 1980, Kretzshmar and Mertens, 1984).

In modelling vertical diffusion by similarity theory, three general descriptions of stability in the atmospheric surface layer can be made. These three groupings are based on the evolution of the atmospheric surface layer and the surface heat flux during the day and night (Figure 1, OME, (1986)). They are;

(i) convective or unstable,

(ii) stable, and

(iii) neutral.

3.1.1 Unstable

Periods when the surface heat flux is positive are convective (greater than 5 W m^{-2} in CRDM). Under convective conditions the air in the atmospheric surface layer is well-mixed due to large eddies generated by surface heating from incoming sunlight. The atmospheric surface layer may be deeper than two kilometres depending on the amount of heating available to drive the deep convective mixing.

3.1.2 Stable

Stable conditions occur when the surface heat flux is negative (less than 5 W m^{-2} in CRDM; or at night; or during winter, when the ground is snow-covered). The mixing in the atmospheric surface layer is very small and the vertical temperature gradient dampens vertical turbulence. The atmospheric surface layer may be very shallow (less than 100 metres) and is influenced principally by surface friction.

3.1.3 Neutral

When the surface heat flux is near zero (between 5 and -5 W m^{-2} in CRDM), the atmosphere is neutral (neither stable nor convective). Atmospheric conditions neither act to enhance nor suppress the generation of turbulence, which is dominated by mechanical shear forces. Mechanically generated turbulence increases with wind speed. In CRDM, conditions with wind speeds greater than 6 m s^{-1} are considered neutral.

3.1.4 Surface Heat Flux

Given the location (latitude and longitude) of the source and the date and time, the surface heat flux, H_0 (W m^{-2}) may be calculated based on the assumption that it is proportional to the net solar radiation plus a small correction for the long wavelength loss of heat from the surface. Cloud cover reduces the net solar radiation reaching the surface and also decreases the long wave losses. The expression used in CRDM for H_0 (Maul, 1980) is as follows;

$$H_o = \alpha R + H_L \qquad (3)$$

where

α is a function of the local surface (= 0.35 in CRDM)

R is the incoming solar radiation (W m^{-2}) which, between local sunrise and sunset, is given by

$$R = 950\ \beta\ (\cos\phi \cos\tau \cos L_r + \sin\phi \sin L_r) \quad (4)$$

and

$$\tau = \pi(t - t_n)/12 \quad (5)$$

$$t_n = 12 + L_d/15 \quad (6)$$

$$\phi = \arctan\{0.4348 \sin[\pi(d - 78)/180]\} \quad (7)$$

$$t_{rise} = t_n - 12 \arccos(-\tan\phi \tan L_r)/\pi \quad (8)$$

$$t_{set} = t_n + 12 \arccos(-\tan\phi \tan L_r)/\pi \quad (9)$$

t is the time of day (decimal hours Greenwich Mean Time, GMT)

L_r is the latitude of the source (degrees)

L_d is the longitude of the source (degrees)

d is the Julian day of the year (1 to 365 or 366)

t_n is the local noon time (GMT)

β is the radiation reduction factor for the incoming solar radiation due to cloud (sky) cover (Table 1, Maul (1980))

t_{rise} is the time of local sunrise (GMT)

t_{set} is the time of local sunset (GMT)

H_L is the long wavelength heat at the surface and is given by

$$H_L = -3.0\ (8.5 - cc) \quad (10)$$

where

cc is the fractional cloud cover of the sky in octants (eighths).

TABLE 1

Cloud Cover Reduction Factors for Incoming Solar Radiation

	Sky Cover Percent	Sky Cover Octants	Reduction Factor
Clear	0.0	0	1.00
	12.5	1	0.89
	25.0	2	0.81
	37.5	3	0.76
	50.0	4	0.72
	62.5	5	0.67
	75.0	6	0.59
	87.5	7	0.45
Fully Overcast	100.0	8	0.23

3.1.5 Horizontal Standard Deviation

CRDM treats horizontal diffusion as Gaussian. However, rather than basing the horizontal standard deviation, σ_y, on a stability class, it is recommended (OH, 1986) that σ_y be related to a directly measured observable, the standard deviation of wind direction, σ_θ, (Pasquill, 1976) an approach that has shown to perform significantly better (Irwin, 1983).

$$\sigma_y = \sigma_\theta \times F$$

where

$$F = 1/\{1 + [(x/1000)/2.5]^{0.5}\}$$

In the absence of wind direction standard deviation, an alternate method of determining σ_y may be used in CRDM. Stability class may be derived as a function of the Monin-Obukhov length and surface roughness length (Figure 2, Golder (1972)). The crosswind standard deviations are then calculated using Briggs' (1973) values, as recommended by the National Working Group (1982).

$$\sigma_y = ax\ (1 + 0.0001x)^{-0.5}$$

where a is determined by stability class as follows.

TABLE 2

Stability Class	a
A	0.22
B	0.16
C	0.11
D	0.08
E	0.06
F	0.04

3.2 Surface Layer Parameters

3.2.1 Surface Roughness Length

The surface roughness length z_0, as its name implies, is a measure of the roughness of the surface and represents the length scale for mechanical turbulence generated in the atmospheric surface layer. It may be approximated as one-thirtieth of the height of the roughness elements such as buildings or trees (OME, 1986). Table 3 (Pasquill (1974) and Seinfeld (1975)) lists z_0 for various surfaces.

TABLE 3

Roughness Lengths for Various Surfaces

Surface	z_0 (cm)
Very smooth (ice, mud flats)	0.001
Snow	0.005
Smooth sea	0.02
Lawn, grass up to 1 cm high	0.03
Lawn, grass up to 5 cm high	1-2
Lawn, grass up to 50 cm high	4-9
Fully grown root crops	14
Urban	100

3.2.2 Friction Velocity

The friction velocity, u_*, represents a measure of the surface frictional force of the wind (ie, the vertical flux of momentum), and is a velocity scale characteristic of the mechanical turbulence.

The friction velocity is given as (Businger, 1973):

$$u_* = k\, u/[\ln(z_m/z_0) - \psi\ (z_m/L)] \qquad (11)$$

where

k is the von Karman constant (= 0.35 in CRDM)

z_m is the height at which the wind measurements are made (m)

and for convective conditions

$$\psi(z_m/L) = 2\ \ln[(1+q)/2] + \ln[(1+q^2)/2] - 2\ \arctan(q) + \pi/2 \qquad (12)$$

where

$$q = [(1 - 15\ z_m)/L]^{0.25} \qquad (13)$$

For stable conditions

$$\psi\ (z_m/L) = -4.7\ z_m/L \qquad (14)$$

and for neutral situations

$$\psi\ (z_m/L) = 0 \qquad (15)$$

3.2.3 Monin-Obukhov Length

The Monin-Obukhov scaling length, L (m), describes the relative effects of mechanically and thermally-induced turbulence. Under unstable conditions, the magnitude of L may be thought of as the height at which mechanically-induced turbulence is approximately equal to thermally-induced turbulence. Above this height thermally-induced turbulence dominates (Businger, 1973).

The Monin-Obukhov length in the convective boundary layer is

$$L = -u_*^3\ T\ \rho\ C_p/(g\ k\ H_0) \qquad (16)$$

where

T is the ambient temperature (degrees Kelvin)

ρ is the air density near the surface ($g\ m^{-3}$) (= 1276 in CRDM)

C_p is the specific heat of dry air at constant pressure ($J\ g^{-1}\ K^{-1}$) (= 1.003 in CRDM)

g is the acceleration due to gravity ($m\ s^{-2}$) (= 9.8 in CRDM)

Using measurements in a stable boundary layer, it has been observed that an empirical relationship exists between the Monin-Obukhov length and the friction velocity (Venkatram, 1980). This relationship was parameterized as,

$$L = 1100\ u_*^2 \qquad (17)$$

where the velocity profile is as given in Section 3.2.2.

When the wind (and hence u_*) is small, the above empirical fit is no longer valid (there are no real solutions). Wind speeds less than the critical wind speed are assumed to be calm. In CRDM, the wind speed is reassigned to be this minimum value.

3.3 Mean Horizontal Wind Speed

The mean horizontal velocity of the plume, $\bar{u}$ is given by

$$\bar{u} = u_* \, [\ln (0.6\bar{z}/z_o) - \psi(0.6\,\bar{z}/L)]/k \qquad (18)$$

where ψ is defined as in equations (12),(14) and (15)

3.4 Mean Particle Height

The mean particle height or the mean height to which the plume has dispersed, $\bar{z}$ is solved from the following equations (van Ulden, 1978)

$$x = 0.74\ \bar{z}\ \{[\ln (0.6\bar{z}/z_o) - \psi(0.6\bar{z}/L)]\{(1-3.5\bar{z}/L)^{-0.5}]\}\ /k^2 \qquad (19)$$

and for stable conditions, $\bar{z}$ is solved from

$$x = 0.74\ \bar{z}\ \{[\ln(0.6\bar{z}/z_o) + 4.9\bar{z}/L](1+4.9\bar{z}/L) + 1.2\bar{z}/L\}\ /k^2 \qquad (20)$$

For the neutral situation $\bar{z}$ is determined by solving

$$x = 0.74\ \bar{z}\ \ln (0.6\bar{z}/z_o)/k^2 \qquad (21)$$

3.5 Release Height

In order to deal with a non-zero release height Batchelor (1964) pointed out that a particle "forgets" its position of release while travelling downwind. Therefore a virtual distance x_o, is calculated such that the particles released at an elevated source height, h, have a mean particle height $\bar{z} = h$ at $x = 0$. Otherwise, for a surface release, $x_o = 0$.

3.6 Dry Deposition

A general treatment of dry deposition is to assume that the rate of dry deposition per unit area, D (units $s^{-1}\ m^{-2}$) is proportional to the ground-level concentration $\chi(x,y,0)$

$$\chi(x,y,0) = 0.73\ Q \exp(-y^2/2\sigma_y^2)/(\sqrt{2\pi}\ \bar{u}\ \bar{z}\ \sigma_y) \qquad (22)$$

Therefore

$$D = v_d \chi (x,y,0) \qquad (23)$$

where

v_d is the dry deposition velocity of the material (m s^{-1}).

3.6.1 Depletion by Dry Deposition

To account for the effect of dry deposition, a source depletion procedure originally suggested by Chamberlain (1960) and described by van der Hoven (1968) is used. This consists of calculating the total dry deposition at each downwind distance x and then subtracting this from the source. From Horst (1974), it seems that the source depletion procedure is adequate for a range of small values of v_d, corresponding to small particles. (For larger v_d values, the surface depletion model should be used).

If the source is $Q = Q(x)$, then integrating equation (23) with respect to y after substituting from equation (22) gives the amount deposited per unit time between x and dx (ie, the amount depleted from the plume).

$$dQ(x)/dx = - \int_{-\infty}^{\infty} v_d \chi(x,y,0)\, dy$$

$$dQ(x) = - 0.73\, v_d\, Q/(\bar{u}\,\bar{z})\, dx \qquad (24)$$

which, for $Q(x = 0) = Q_o$ has the solution

$$Q(x) = Q_o \exp\left[-0.73\, v_d \left(\int_o^x 1/(\bar{u}\,\bar{z})\, dx'\right)\right] \qquad (25)$$

3.7 Wet Deposition

Precipitation removes material over the plume volume in proportion to the rate of precipitation and the local concentration of material within the plume. At any downwind distance, the rate of wet deposition per unit area, W (units s^{-1} m^{-2}) will be

$$W = \lambda_w \int_o^{\infty} \chi(x,y,z)\, dz$$

where

λ_w is a washout coefficient that is a function of the precipitation type and rate (s^{-1}).

3.7.1 Depletion by Wet Deposition

The depletion of the plume by wet deposition is considered to occur uniformly over the plume volume and so the shape of the plume does not change (Gifford, 1975).

If the source $Q = Q(x)$ is depleted by wet deposition, then

$$Q(x) = Q_o \exp(-\lambda_w x/u),$$

an exponential decay which can be treated similarly to radioactive decay.

3.8 Computer Implementation

CRDM was written in Fortran in a structured and modular fashion. It was easily incorporated into the ERP computer code as a result. A version of CRDM exists which can be used independently of the ERP program. CRDM is run on an IBM-PC compatible microcomputer and also on the Environmental Science Section's MicroVAX II super microcomputer. Appendix A contains a complete program listing of CRDM as it is used in ERP. The current version of ERP does not calculate radiation dose resulting from ground contamination. Therefore the calculation of dry and wet deposition is not included in CRDM at the present time.

3.9 Sensitivity Analysis

A study of the sensitivity of CRDM to variation of input parameters has been completed (Camacho, 1986). The results of this work show that the most sensitive input variable is wind speed and the least sensitive is the ambient temperature. Also, large values of normalized concentrations (dilution factors) are likely to occur for small values of wind speed and under highly stable conditions (ie, during nighttime). Finally, it was shown that for every 1% overall error in the input values, an error between 2.5% and 10% should be expected in the output value and that this factor can be much larger in certain situations.

4.0 RECOMMENDATIONS FOR FUTURE WORK

To lend further credibility to the use of CRDM for dispersion calculations for Ontario Hydro nuclear generating sites, a comparison of CRDM results with field data should be made. Preliminary comparisons have been made of CRDM calculations to data collected in a pilot tracer study at Wesleyville using a near ground-level release, (Ogram & Edwards, 1985) (see Table 4). As can be seen, the agreement was good. (In the same comparison study, Gaussian models tended to overpredict centreline concentrations). It is recommended that a more extensive comparison be undertaken with the data from the tracer study recently completed at Darlington NGS (Ogram 1986).

TABLE 4

COMPARISON OF MEASURED PLUME CENTRELINE DILUTION FACTORS χ/Q ($s\ m^{-3}$) WITH CRDM PREDICTIONS

Date/Time	Observed χ/Q	CRDM Predictions[a,b] χ/Q (1)	(2)
Oct 14/84 (unstable)			
1000-1100	8.7×10^{-7}	7.3×10^{-7}	7.7×10^{-7}
1100-1200	5.5×10^{-7}	9.2×10^{-7}	8.1×10^{-7}
Nov 16/84 (neutral)			
0900-1000	1.7×10^{-6}	2.2×10^{-6}	1.7×10^{-6}
1000-1100	1.7×10^{-6}	1.9×10^{-6}	1.3×10^{-6}
1100-1200	1.2×10^{-6}	1.8×10^{-6}	1.0×10^{-6}
1200-1300	1.5×10^{-6}	1.3×10^{-6}	9.1×10^{-7}

[a] Roughness length (z_o) assumed to be 40 cm

[b](1) uses Briggs (1973) values for σ_y

(2) uses the standard deviation of wind direction, Pasquill (1976)

The Darlington tracer study was initiated to examine the effect of building wakes on atmospheric dispersion. Currently CRDM does not include building wake effects. It is recommended that the correct manner in which to account for building wake in CRDM be examined. This is expected to lead to significantly lower predicted centre-line concentrations at short travel distances.

In the most recent nuclear contingency exercise held at Bruce NGS 'B', a number of suggestions for improvements to ERP were made. At the Bruce station emergency operations centre (EOC), the users of ERP requested that a computerized meteorological data acquisition system be implemented for ERP. Such a system would reduce the user input requirements, a desirable goal for the station EOC.

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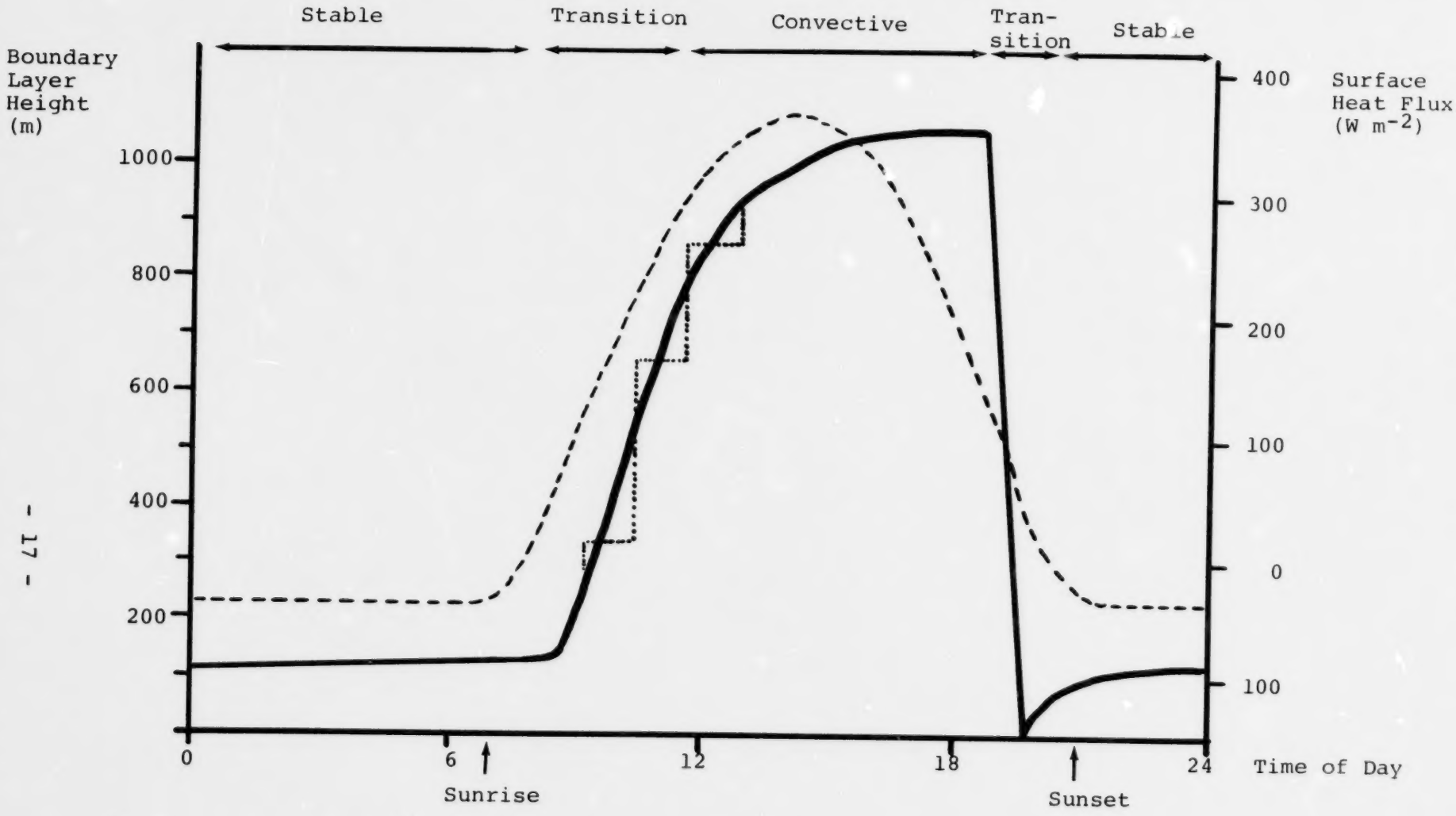

FIGURE 1

Schematic diagram of the evolution of the atmospheric surface layer and of the surface heat flux sketched as functions of the time of day. The left axis shows the scale of the boundary layer height. The right axis presents the scale of the surface heat flux, H_o. The dark solid line denotes the height of the boundary layer. The dotted line shows a stepwise steady state approximation to the boundary layer height applied during transition periods. The surface heat flux is plotted using a dashed line.

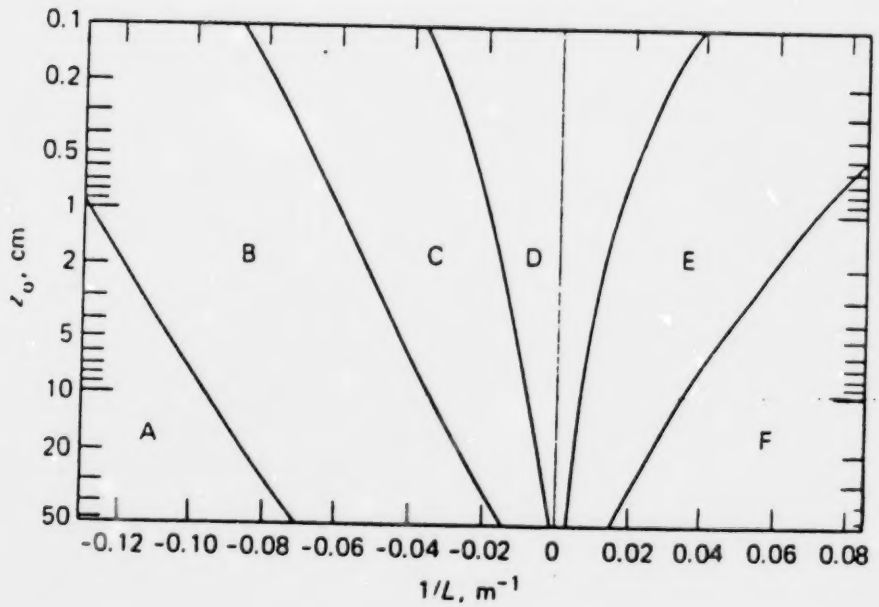

FIGURE 2

Curves showing Pasquill's turbulence types as a function of the Monin–Obukhov stability length and the aerodynamic roughness length. A, extremely unstable conditions; B, moderately unstable conditions; C, slightly unstable conditions; D, neutral conditions (applicable to heavy overcast day or night); E, slightly stable conditions; F, moderately stable conditions. [From D. Golder, Relations Among Stability Parameters in the Surface Layer, *Boundary-Layer Meteorol.*, 3: 56 (1972).]

APPENDIX A

CRDM COMPUTER PROGRAM LISTING

crdm.for

```
    1       SUBROUTINE CRDM(LR,LW)
    2 C
    3 C Purpose: Continuous Release Dispersion Model
    4 C
    5 C Calls to: RDCON
    6 C           RDSTE
    7 C           RDMET
    8 C           CLTME
    9 C           CLXQ
   10 C           WRTXQ
   11 C
   12 C Common blocks: /CNSTS/
   13 C                /STEFL/
   14 C                /METFL/
   15 C                /XQFL/
   16 C                /ERRFL/
   17 C
   18 C Technical Description: CRDM was developed for use in the
   19 C   Province of Ontario Nuclear Emergency Plan. It calculates
   20 C   the concentrations for continuous release of passive
   21 C   contaminants from sources near to the ground. CRDM uses an
   22 C   approach based on similarity theory to describe the
   23 C   vertical growth of the plume, but treats lateral diffusion
   24 C   as Gaussian.
   25 C
   26 C Versions:
   27 C   Original - July, 1983 for Pickering Exercise '83
   28 C   Revised  - Sept, 1985 for Pickering Exercise '85
   29 C   Revised  - July, 1986 for Bruce '86
   30 C
   31       INTEGER LR,LW
   32 C
   33       REAL PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   34       COMMON/CNSTS/PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   35 C
   36       REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
   37       COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
   38 C
   39       REAL TA,U,WD,SIGT,RAIN
   40       INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
   41       LOGICAL LRAIN,LSNOW
   42       COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
   43      *             CLOUD,STB,LRAIN,LSNOW
   44 C
   45       REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
   46       INTEGER NLOC
   47       COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
   48 C
   49       INTEGER IERR,MESNM
   50       LOGICAL ECHO,ERROR
   51       COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
   52 C
   53 C Read the constants file
   54 C
   55       CALL RDCON(LR,LW)
   56       IF(ERROR) GOTO 900
```

```
C
C Read the site data
C
      CALL RDSTE(LR,LW)
      IF(ERROR) GOTO 900
C
C Read the meteorological data
C
      CALL RDMET(LR,LW)
      IF(ERROR) GOTO 900
C
C Calculate sunrise, sunset, local noon and Julian day
C
      CALL CLTME(LAT,LON,YEAR,MONTH,DAY,TRISE,TSET,TNOON,JDAY)
C
C Calculate the results
C
      CALL CLXQ(LR,LW)
      IF(ERROR) GOTO 900
C
C Save the results
C
      CALL WRTXQ(LR,LW)
C
 900  RETURN
      END
```

rdcon.for

```
    1       SUBROUTINE RDCON(LR,LW)
    2 C
    3 C Purpose: Read the constants file
    4 C
    5 C Called by: CRDM
    6 C
    7 C Parameter descriptions:
    8 C     LR - logical unit number for read device <in>
    9 C     LW - logical unit number for write device <in>
   10 C
   11 C Common blocks: /CNSTS/
   12 C                /ERRFL/
   13 C
   14 C I/O files: CNSTS.DAT <in>
   15 C
   16       INTEGER LR,LW
   17 C
   18       REAL PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   19       COMMON/CNSTS/PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   20 C
   21       INTEGER IERR,MESNM
   22       LOGICAL ECHO,ERROR
   23       COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
   24 C
   25 C Open file
   26 C
   27       LC=10
   28       MESNM=1
   29       OPEN(LC,FILE='CNSTS.DAT',STATUS='OLD',IOSTAT=IERR,ERR=900)
   30 C
   31 C Read constant values
   32 C
   33       MESNM=2
   34       READ(LC,1000,ERR=900) PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   35       IF(ECHO) WRITE(LW,1000) PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   36  1000 FORMAT(7(10X,F14.7/),10X,F14.7)
   37       GOTO 999
   38 C
   39  900  ERROR=.TRUE.
   40 C
   41  999  CLOSE(LC)
   42       RETURN
   43       END
```

rdste.for

```
    1       SUBROUTINE RDSTE(LR,LW)
    2 C
    3 C Purpose: Read the site data
    4 C
    5 C Called by: CRDM
    6 C
    7 C Parameter descriptions:
    8 C     LR - logical unit number for read device (in)
    9 C     LW - logical unit number for write device (in)
   10 C
   11 C Common blocks: /STEFL/
   12 C                /ERRFL/
   13 C
   14 C I/O files: CNSTS.DAT (in)
   15 C
   16       INTEGER LR,LW
   17 C
   18       REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
   19       COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
   20 C
   21       INTEGER IERR,MESNM
   22       LOGICAL ECHO,ERROR
   23       COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
   24 C
   25 C Open file
   26 C
   27       LS=11
   28       MESNM=3
   29       OPEN(LS,FILE='SITE.DAT',STATUS='OLD',IOSTAT=IERR,ERR=900)
   30 C
   31 C Read site data
   32 C
   33       MESNM=4
   34       READ(LS,1000,ERR=900) LAT,LON,SRCHGT,Z0,ZM
   35       IF(ECHO) WRITE(LW,1000) LAT,LON,SRCHGT,Z0,ZM
   36  1000 FORMAT(4(10X,F9.2/),10X,F9.2)
   37       GOTO 999
   38 C
   39  900  ERROR=.TRUE.
   40 C
   41  999  CLOSE(LS)
   42       RETURN
   43       END
```

rdmet.for

```
      SUBROUTINE RDMET(LR,LW)
C
C Purpose: Read the meteorological data
C
C Called by: CRDM
C
C Parameter descriptions:
C     LR - logical unit number for read device (in)
C     LW - logical unit number for write device (in)
C
C Common blocks: /METFL/
C                /XQFL/
C                /ERRFL/
C
C I/O files: MET.DAT (in)
C
      INTEGER LR,LW
C
      REAL TA,U,WD,SIGT,RAIN
      INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
      LOGICAL LRAIN,LSNOW
      COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
     *             CLOUD,STB,LRAIN,LSNOW
C
      REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
      INTEGER NLOC
      COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
C
      INTEGER IERR,MESNM
      LOGICAL ECHO,ERROR
      COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
C
      INTEGER ISTART,ISTOP,INC,Z,DWN,CRS
C
C Open file
C
      LM=12
      MESNM=5
      OPEN(LM,FILE='MET.DAT',STATUS='OLD',IOSTAT=IERR,ERR=900)
C
C Read met data
C
      MESNM=6
      READ(LM,1000,ERR=900) YEAR,MONTH,DAY,TIME,CLOUD,U,WD,TA,SIGT,
     *                      STB,LRAIN,RAIN,LSNOW,ISTART,ISTOP,INC,Z
      IF(ECHO) WRITE(LW,1000) YEAR,MONTH,DAY,TIME,CLOUD,U,WD,TA,SIGT,
     *                      STB,LRAIN,RAIN,LSNOW,ISTART,ISTOP,INC,Z
 1000 FORMAT(5(10X,I6/),4(10X,F9.2/),10X,I6/15X,L1/10X,F9.2/15X,L1,
     *       4(/10X,I6))
C
C Store locations
C
      MESNM=7
      J=0
      DO 100 I=ISTART,ISTOP,INC
          J=J+1
```

```
 57            IF(J.GT.50) GOTO 900
 58            LOC(J,1)=FLOAT(I)
 59            LOC(J,2)=0.0
 60            LOC(J,3)=FLOAT(Z)
 61            IF(ECHO) WRITE(LW,1005) (LOC(J,K),K=1,3)
 62  1005      FORMAT(1X,3F10.2)
 63   100  CONTINUE
 64 C
 65   200  CONTINUE
 66            MESNM=8
 67            READ(LM,1010,END=300,ERR=900) DWN,CRS,Z
 68  1010      FORMAT(10X,3(I6))
 69            IF(ECHO) WRITE(LW,1010) DWN,CRS,Z
 70            MESNM=7
 71            J=J+1
 72            IF(J.GT.50) GOTO 900
 73            LOC(J,1)=FLOAT(DWN)
 74            LOC(J,2)=FLOAT(CRS)
 75            LOC(J,3)=FLOAT(Z)
 76            GOTO 200
 77 C
 78   300  NLOC=J
 79        GOTO 999
 80 C
 81   900  ERROR=.TRUE.
 82 C
 83   999  CLOSE(LM)
 84        RETURN
 85        END
```

cltme.for

```
    1       SUBROUTINE CLTME(LR,LD,YY,MM,DD,TR,TS,TN,JD)
    2 C
    3 C Purpose: Calculates Julian day and times of local sunrise,sunset
    4 C          and noon.
    5 C
    6 C Called by: CRDM
    7 C
    8 C Calls to: CLJD
    9 C
   10 C Parameter descriptions:
   11 C     LR  - site latitude (degrees) <in>
   12 C     LD  - site longitude (degress) <in>
   13 C     YY  - current year (YYYY) <in>
   14 C     MM  - current month (MM,1-12) <in>
   15 C     DD  - current day (DD,1-31) <in>
   16 C     TR  - time of local sunrise <out>
   17 C     TS  - time of local sunset <out>
   18 C     TN  - time of local noon <out>
   19 C     JD  - Julian day
   20 C
   21       REAL LR,LD,TR,TS,TN
   22       INTEGER YY,MM,DD,JD
   23 C
   24       REAL PIE,LRR
   25       DATA PIE/3.1415927/
   26 C
   27 C Calculate the Julian date
   28 C
   29       CALL CLJD(YY,MM,DD,JD)
   30 C
   31 C Calculate local noontime (GMT)
   32 C
   33       TN=12.0+LD/15.0
   34 C
   35 C Change latitude from degrees to radians
   36 C
   37       LRR=LR*PIE/180.0
   38 C
   39 C Calculate local sunrise
   40 C
   41       PHI=ATAN(0.4348*SIN(PIE*(JD-78.0)/180.0))
   42       TEMP=12.0/PIE*ACOS(-TAN(PHI)*TAN(LRR))
   43       TR=TN-TEMP
   44 C
   45 C Calculate local sunset
   46 C
   47       TS=TN+TEMP
   48 C
   49       RETURN
   50       END
```

cljd.for

```
    1       SUBROUTINE CLJD(YY,MM,DD,JD)
    2 C
    3 C Purpose: Calculates the Julian day.
    4 C
    5 C Called by: CLTME
    6 C
    7 C Parameter descriptions:
    8 C       YY - year (YYYY) <in>
    9 C       MM - month (MM)  <in>
   10 C       DD - day (DD)    <in>
   11 C       JD - Julian day  <out>
   12 C
   13       INTEGER YY,MM,DD,JD
   14 C
   15       INTEGER DAYS(12)
   16       DATA DAYS/31,28,31,30,31,30,31,31,30,31,30,31/
   17 C
   18       IYR=YY/4
   19       ILEAP=YY-(IYR*4)
   20       IF(ILEAP.EQ.0) DAYS(2)=29
   21       JD=0
   22 C
   23       DO 10 J=1,MM-1
   24           JD=JD+DAYS(J)
   25  10       CONTINUE
   26       JD=JD+DD
   27 C
   28       RETURN
   29       END
```

clxq.for

```
      SUBROUTINE CLXQ(LR,LW)
C
C Purpose: Calculate concentrations
C
C Called by: CRDM
C
C Calls to: CLHLU
C           FSZB
C           FUZB
C           CLSGY
C           CLZB
C           CLUB
C
C Parameter descriptions:
C     LR - logical unit number for read device (in)
C     LW - logical unit number for write device (in)
C
C Common blocks: /CNSTS/
C                /STEFL/
C                /METFL/
C                /XQFL/
C                /ERRFL/
C
      INTEGER LR,LW
C
      REAL PI,RHO,CP,ALPHA,G,K1,BETA,AU0
      COMMON/CNSTS/PI,RHO,CP,ALPHA,G,K1,BETA,AU0
C
      REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
      COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
C
      REAL TA,U,WD,SIGT,RAIN
      INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
      LOGICAL LRAIN,LSNOW
      COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
     &             CLOUD,STB,LRAIN,LSNOW
C
      REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
      INTEGER NLOC
      COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
C
      INTEGER IERR,MESNM
      LOGICAL ECHO,ERROR
      COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
C
      DO 100 I=1,NLOC
          XQ(I)=0.0
          AZB(I)=0.0
  100 CONTINUE
C
C Calculate the heat flux, Monin-Obukhov length and
C friction velocity
C
      CALL CLHLU
C
C Calculate the virtual distance X0 for an elevated source
```

```
 57 C
 58         IF(SRCHGT.NE.0) THEN
 59             IF(1/ML.GT.0) THEN
 60                 X0=FSZB(ML,K1,Z0,0,SRCHGT)
 61             ELSE
 62                 X0=FUZB(ML,K1,Z0,0,SRCHGT)
 63             ENDIF
 64         ELSE
 65             X0=0
 66         ENDIF
 67 C
 68  300    I=1
 69  400    IF(I.GT.NLOC) GOTO 500
 70 C
 71 C Calculate sigma Y
 72 C
 73             CALL CLSGY(LOC(I,1),SGY)
 74             SIGY(I)=SGY
 75 C
 76 C Calculate the mean particle height
 77 C
 78             CALL CLZB(ML,K1,Z0,LOC(I,1)+X0,ZB)
 79             AZB(I)=ZB
 80             IF(ZB.LE.0) GOTO 450
 81 C
 82 C Calculate the mean horizontal velocity
 83 C
 84             CALL CLUB(US,ML,K1,Z0,LOC(I,1),LOC(I,2),ZB,UB)
 85 C
 86 C Calculate the dilution factor
 87 C
 88             DN=SQRT(2*PI)*UB*ZB*SIGY(I)
 89             CRS=ABS(LOC(I,2))
 90             EARG1=-(0.66*LOC(I,3)/ZB)**1.5
 91             EARG2=CRS**2/(2*SIGY(I)**2)
 92             IF(EARG1-EARG2.LT.-75.0) GOTO 450
 93             XQ(I)=0.73/DN*EXP(EARG1-EARG2)
 94  450        I=I+1
 95             GOTO 400
 96  500     CONTINUE
 97         GOTO 999
 98 C
 99  900    ERROR=.TRUE.
100 C
101  999    RETURN
102         END
```

clhlu.for

```
      SUBROUTINE CLHLU
C
C Purpose: Calculate heat flux, Monin-Obukhov length and
C          friction velocity
C
C Called by: CLXQ
C
C Calls to: CLHF
C           PSI
C
C Common blocks: /CNSTS/
C                /STEFL/
C                /METFL/
C                /XQFL/
C                /ERRFL/
C
      REAL PI,RHO,CP,ALPHA,G,K1,BETA,AU0
      COMMON/CNSTS/PI,RHO,CP,ALPHA,G,K1,BETA,AU0
C
      REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
      COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
C
      REAL TA,U,WD,SIGT,RAIN
      INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
      LOGICAL LRAIN,LSNOW
      COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
     .             CLOUD,STB,LRAIN,LSNOW
C
      REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
      INTEGER NLOC
      COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
C
      INTEGER IERR,MESNM
      LOGICAL ECHO,ERROR
      COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
C
C Calculate the heat flux
C
      CALL CLHF
C
C Convective (unstable) conditions (HF>5)
C
      IF(HF.GT.5.0) THEN
C
C Initial guess
C
          US=U/12.0
          ITER=0
C
C Calculate Monin-Obukhov length and friction velocity iteratively
C
  100     CONTINUE
              ITER=ITER+1
              ML=-RHO*CP*TA*US**3/(G*K1*HF)
              Q=(1.0-15.0*ZM/ML)**0.25
              UOLD=US
```

```
                US=U*K1/(ALOG(ZM/Z0)-PSI(Q))
C
C Use tolerance of 1%
C
                TOL=ABS(UOLD/US-1.0)
                IF(TOL.LE.0.01.AND.ITER.NE.1) GOTO 200
                IF(ITER.LE.50) GOTO 100
C
C If more than 50 iterations, then assume no convergence
C
                    MESNM=9
                    GOTO 900
 200        CONTINUE
        ELSE
C
C Stable conditions (HF<-5)
C
            IF(HF.LE.-5.0) THEN
                UMIN=SQRT(18.8*ALOG(ZM/Z0)*ZM/1100.0/K1**2.0)
                IF(U.GE.UMIN) THEN
                    U0=SQRT(BETA*ZM/(K1*AU0))
                    CDN=K1/ALOG(ZM/Z0)
                    SARG=1.0-(2.0*U0/(SQRT(CDN)*U))**2.0
                    US=CDN*U*(0.5+0.5*SQRT(SARG))
                ELSE
                    US=UMIN*K1*0.5/ALOG(ZM/Z0)
                ENDIF
                ML=AU0*US*US
            ENDIF
        ENDIF
C
C Normal conditions (-5<=HF<=5, ML>500 m, U>6 m/s)
C
        IF((HF.GE.-5.0.AND.HF.LE.5.0).OR.(ML.GT.500).OR.(U.GT.6.0)) THEN
            IF(U.LT.1.5) U=1.5
            US=K1*U/ALOG(ZM/Z0)
            ML=-RHO*CP*TA*US**3/(G*K1*HF)
        ENDIF
        GOTO 999
C
 900    ERROR=.TRUE.
C
 999    RETURN
        END
        REAL FUNCTION PSI(A)
C
C Purpose: Calculate function for unstable conditions
C
C Called by: CLHLU
C
C Parameter description:
C     A - argument
C
        REAL A
C
        PI2=3.1415927/2.0
        PSI=2.0*ALOG((1.0+A)/2.0)+ALOG((1.0+A**2.0)/2.0)-2.0*ATAN(A)+PI2
C
```

```
115         RETURN
116         END
```

clhf.for

```
    1       SUBROUTINE CLHF
    2 C
    3 C Purpose: Calculate heat flux
    4 C
    5 C Called by: CLHLU
    6 C
    7 C Common blocks: /CNSTS/
    8 C                /STEFL/
    9 C                /METFL/
   10 C                /XQFL/
   11 C                /ERRFL/
   12 C
   13       REAL PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   14       COMMON/CNSTS/PI,RHO,CP,ALPHA,G,K1,BETA,AU0
   15 C
   16       REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
   17       COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
   18 C
   19       REAL TA,U,WD,SIGT,RAIN
   20       INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
   21       LOGICAL LRAIN,LSNOW
   22       COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
   23      .             CLOUD,STB,LRAIN,LSNOW
   24 C
   25       REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
   26       INTEGER NLOC
   27       COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
   28 C
   29       INTEGER IERR,MESNM
   30       LOGICAL ECHO,ERROR
   31       COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
   32 C
   33       REAL RF(9),LR
   34       DATA RF/1.0,0.89,0.81,0.76,0.72,0.67,0.59,0.45,0.23/
   35 C
   36 C Change the time (hhmm,GMT) to decimal hours (GMT)
   37 C
   38       FT=FLOAT(TIME)
   39       IHRS=IFIX(FT/100.0)
   40       ISEC=TIME-IHRS*100
   41       TGMT=FLOAT(IHRS)+FLOAT(ISEC)/60.0
   42 C
   43       PHI=ATAN(0.4348*SIN(PI*(FLOAT(JDAY)-78.0)/180.0))
   44       TAU=PI*(TGMT-TNOON)/12.0
   45       LR=LAT*PI/180.0
   46       IC=CLOUD+1
   47 C
   48 C Stable conditions for nighttime (R=0) or snow cover (ALPHA=0)
   49 C
   50       IF(TGMT.LT.TRISE.OR.TGMT.GT.TSET.OR.LSNOW) THEN
   51           HF=-6
   52       ELSE
   53 C
   54 C Calculate the incoming solar radiation (Watts or joules/s)
   55 C
   56           R=RF(IC)*950.0*(COS(PHI)*COS(TAU)*COS(LR)+SIN(PHI)*SIN(LR))
```

```
C
C Calculate the long wavelength heat loss at the surface
C
            HL=-3.0*(8.5-FLOAT(CLOUD))
C
C Calculate the surface heat flux
C
            HF=ALPHA*R+HL
            WRITE(*,992) PHI,TAU,R,HL,HF
 992        FORMAT(/' PHI(LAMDA) =',1PE14.3/' TAU(TILTA) =',1PE14.3/
     *              ' R =',1PE14.3/' HL =',1PE14.3/' HF =',1PE14.3)
         ENDIF
         GOTO 999
C
 900     ERROR=.TRUE.
C
 999     RETURN
         END
```

clsgy.for

```
      SUBROUTINE CLSGY(X,SGY)
C
C Purpose: Calculate crosswind standard deviation
C
C Called by: CLXQ
C
C Calls to: CLSTB
C
C Parameter description:
C      X - downwind direction (m)   <in>
C    SGY - crosswind standard deviation (m)  <out>
C
C Common blocks: /METFL/
C                /XQFL/
C                /ERRFL/
C
      REAL X,SGY
C
      REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
      COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
C
      REAL TA,U,WD,SIGT,RAIN
      INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
      LOGICAL LRAIN,LSNOW
      COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
     *             CLOUD,STB,LRAIN,LSNOW
C
      REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
      INTEGER NLOC
      COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
C
      INTEGER IERR,MESNM
      LOGICAL ECHO,ERROR
      COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
C
      REAL STBV(6)
      DATA STBV/0.22,0.16,0.11,0.08,0.06,0.04/
C
      IF(SIGT.EQ.0.0) THEN
C
C Calculate stability category using Monin-Obukhov length and
C surface roughness
C
          CALL CLSTB(ML,Z0,STB)
C
C Calculate sigma y using Brigg's values as recommended by the
C National Working Group on Radionuclide Transport
C
          SGY=(STBV(STB)*X)/(SQRT(1.0+0.0001*X))
      ELSE
C
C Calculate sigma y using sigma theta
C
          FX=1.0/(1.0+SQRT((X/1000.0)/2.5))
          SGY=SIGT*FX*X
      ENDIF
```

```
C
      RETURN
      END
C
      SUBROUTINE CLSTB(MOL,Z0M,SC)
C
C Purpose: Estimates stability category as a function of the
C          Monin-Obukhov length and surface roughness
C
C Called by: CLSGY
C
C Parameter description:
C    MOL - Monin-Obukhov length (m)  <in>
C    Z0M - surface roughness (m)     <in>
C     SC - stability category (1-6 <==> A-F)  <out>
C
      REAL MOL,Z0M
      INTEGER SC
C
      REAL F(6),K(6),MNN,MN
      DATA F/0.01534,0.01022,0.00767,0.0,-0.00767,-0.01278/,
     *     K/-0.14,-0.09,-0.04,0.0,0.04,0.08/
C
      MNN=1.0E+30
      DO 10 I=1,6
          MN=1.0/MOL-(ALOG(Z0M*100.0)*F(I)+K(I))
          IF(ABS(MNN).GT.ABS(MN)) THEN
              MNN=MN
              SC=I
          ENDIF
 10   CONTINUE
C
      RETURN
      END
```

clzb.for

```
      SUBROUTINE CLZB(MOL,CK1,Z0M,DWN,ZB)
C
C Purpose: Calculate the mean particle height
C
C Called by: CLXQ
C
C Calls to: FUZB
C           FSZB
C
C Parameter descriptions:
C    MOL: Monin-Obukhov length (m)  <in>
C     ZB: mean particle heights for each downwind distance (m)  <out>
C    CK1: von Karman constant  <out>
C    Z0M: surface roughness (m)  <out>
C    DWN: downwind distance (m)  <out>
C
      REAL MOL,CK1,Z0M,DWN,ZB
C
C Solve for ZB
C
      ZB=-1.0
      XTOL=0.0001
      A=0.0001
      B=4000.0
      IFLAG=0
      N=1
C
      IF(A/MOL.LT.0) THEN
          FA=FUZB(MOL,CK1,Z0M,DWN,A)
      ELSE
          FA=FSZB(MOL,CK1,Z0M,DWN,A)
      ENDIF
C
C Check for sign change
C
      IF(B/MOL.LT.0) THEN
          FB=FUZB(MOL,CK1,Z0M,DWN,B)
      ELSE
          FB=FSZB(MOL,CK1,Z0M,DWN,B)
      ENDIF
      IF(FA*FB.LE.0) GOTO 10
          IFLAG=2
          GOTO 50
 10   ERRO=ABS(B-A)
 20   ERRO=ERRO/2
C
C Check for sufficiently small interval
C
      IF(ERRO.LT.XTOL) GOTO 50
      XM=(A+B)/2
C
C Check for unreasonable error requirement
C
      IF(XM+ERRO.EQ.XM) GOTO 40
          IF(XM/MOL.LT.0) THEN
              FM=FUZB(MOL,CK1,Z0M,DWN,XM)
```

```
57            ELSE
58                FM=FSZB(MOL,CK1,Z0M,DWN,XM)
59            ENDIF
60 C
61        N=N+1
62 C
63 C Change to a new interval
64 C
65        IF(FA*FM.LE.0) GOTO 30
66            A=XM
67            FA=FM
68            GOTO 20
69 C
70  30    B=XM
71        GOTO 20
72 C
73  40    IFLAG=1
74 C
75  50    IF(IFLAG.NE.2) ZB=(A+B)/2
76 C
77        RETURN
78        END
79 C
80        FUNCTION FSZB(MOL,CK1,Z0M,DWN,X)
81 C
82 C Purpose: Calculate mean particle height for stable conditions.
83 C
84 C Called by: CLXQ
85 C             CLZB
86 C
87 C P   eter descriptions:
88 C     OL: Monin-Obukhov length (m)  <in>
89 C     K1: von Karman constant       <in>
90 C     Z0M: surface roughness (m)    <in>
91 C     WN: downwind distance (m)     <in>
92 C       X: mean particle height (m) <in>
93 C
94        REAL MOL,CK1,Z0M,DWN,X
95 C
96        FSZB=(0.74/CK1**2)*X*((ALOG(0.6*X/Z0M)+4.9*X/MOL)*
97       *    (1+4.9*X/MOL)+1.2*X/MOL)-DWN
98 C
99        RETURN
100       END
101 C
102       FUNCTION FUZB(MOL,CK1,Z0M,DWN,X)
103 C
104 C Purpose: Calculate mean particle height for unstable conditions.
105 C
106 C Called by: CLXQ
107 C             CLZB
108 C
109 C Calls to: PSI
110 C
111 C Parameter descriptions:
112 C    MOL: Monin-Obukhov length (m)  <in>
113 C    CK1: constant                  <in>
114 C    Z0M: surface roughness (m)     <in>
```

```
115 C     DWN: downwind distance (m)      <in>
116 C       X: mean particle height (m)   <in>
117 C
118         REAL MOL,CK1,Z0M,DWN,X
119 C
120         A=(1-15*(0.6*X/MOL))**0.25
121         FUZB=(0.74/CK1**2)*X*((ALOG(0.6*X/Z0M)-PSI(A))/
122        *    (1-3.5*X/MOL)**0.5)-DWN
123 C
124         RETURN
125         END
126 C
127         SUBROUTINE CLUB(USS,MOL,CK1,Z0M,DWN,CRS,ZB,UB)
128 C
129 C     This subroutine calculates mean horizontal velocity.
130 C
131 C Input-
132 C     USS: friction velocity (m/s)
133 C     MOL: Monin-Obukhov length (m)
134 C     CK1: constant
135 C     Z0M: surface roughness (m)
136 C     DWN: downwind distance (m)
137 C     CRS: crosswind distance (m)
138 C      ZB: mean particle height (m)
139 C
140 C Output-
141 C      UB: mean horizontal velocity (m/s)
142 C
143         REAL USS,MOL,CK1,Z0M,DWN,CRS,ZB,UB
144 C
145         IF(ZB/MOL.GE.0) GOTO 10
146             Z=ZB
147             IF(DWN.EQ.0.AND.CRS.EQ.0) Z=0
148             A=(1-15*(0.6*Z/MOL))**0.25
149             UB=(USS/CK1*(ALOG(0.6*ZB/Z0M)-PSI(A)))
150             GOTO 20
151 C
152   10    UB=(USS/CK1*(ALOG(0.6*ZB/Z0M)+4.7*ZB/MOL))
153 C
154   20    RETURN
155         END
```

wrtxq.for

```
      SUBROUTINE WRTXQ(LR,LW)
C
C Purpose: Write results
C
C Called from: CRDM
C
C Common blocks: /CNSTS/
C                /STEFL/
C                /METFL/
C                /XQFL/
C                /ERRFL/
C
      INTEGER LR,LW
C
      REAL PI,RHO,CP,ALPHA,G,K1,BETA,AU0
      COMMON/CNSTS/PI,RHO,CP,ALPHA,G,K1,BETA,AU0
C
      REAL LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
      COMMON/STEFL/LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
C
      REAL TA,U,WD,SIGT,RAIN
      INTEGER YEAR,MONTH,DAY,JDAY,TIME,CLOUD,STB
      LOGICAL LRAIN,LSNOW
      COMMON/METFL/TA,U,WD,SIGT,RAIN,YEAR,MONTH,DAY,JDAY,TIME,
     *             CLOUD,STB,LRAIN,LSNOW
C
      REAL US,HF,ML,SIGY(50),AZB(50),LOC(50,3),XQ(50)
      INTEGER NLOC
      COMMON/XQFL/US,HF,ML,SIGY,AZB,LOC,XQ,NLOC
C
      INTEGER IERR,MESNM
      LOGICAL ECHO,ERROR
      COMMON/ERRFL/IERR,MESNM,ECHO,ERROR
C
      OPEN(LF,FILE='NEADM.DAT',IOSTAT=IERR,ERR=900)
C
C Write the constants file
C
      MESNM=10
      WRITE(LF,1000,ERR=900) PI,RHO,CP,ALPHA,G,K1,BETA,AU0
 1000 FORMAT(/' Constants File'/' PI   ',F14.7/' RHO  ',F14.7/
     *       ' CP   ',F14.7/' ALPHA',F14.7/' G    ',F14.7/
     *       ' K1   ',F14.7/' BETA ',F14.7/' AU0  ',F14.7/)
C
C Write the site data
C
      MESNM=11
      WRITE(LF,1010,ERR=900) LAT,LON,SRCHGT,Z0,ZM,TRISE,TSET,TNOON
 1010 FORMAT(/' Site Data'/' LAT    ',F9.2/' LON    ',F9.2/
     *       ' SRCHGT',F9.2/' Z0     ',F9.2/' ZM     ',F9.2/
     *       ' TRISE ',F9.2/' TSET   ',F9.2/' TNOON ',F9.2/)
C
C Write the meteorological data
C
      MESNM=12
      WRITE(LF,1020,ERR=900) YEAR,MONTH,DAY,JDAY,TIME,CLOUD,U,WD,TA,
```

```
     *                          SIGT,STB,LRAIN,RAIN,LSNOW
1020 FORMAT(/' Met Data'/' YEAR  ',I6/' MONTH ',I6/' DAY   ',I6/
     *       ' JDAY  ',I6/' TIME  ',I6/' CLOUD ',I6/' U     ',F9.2/
     *       ' WD    ',F9.2/' TA    ',F9.2/' SIGT  ',F9.2/' STB   ',
     *       I6/' LRAIN ',5X,L1/' RAIN  ',F9.2/' LSNOW',6X,L1/)
C
C Write the results
C
      MESNM=13
      WRITE(LF,1030,ERR=900) US,HF,ML
1030 FORMAT(/' Results'/ ' US    ',F9.2/' HF    ',F9.2/' ML    ',F9.2/
     *      /8X,'DWN',4X,'CRS',4X,'Z',8X,'XQ',8X,'SY',6X,'ZB',7X,'EFF',
     *      6X,'THY',4X,'GS')
      MESNM=14
      DO 100 I=1,NLOC
          IF(AZB(I).NE.-1.0.AND.XQ(I).NE.0.0) THEN
              SZ=AZB(I)/0.8
              IF(LOC(I,2).LT.10.0) THEN
                  SYZ=SQRT(SIGY(I)*SZ)
              ELSE
                  SYZ=(SIGY(I)*(SZ**3.0))**(0.25)
              ENDIF
              IF(LOC(I,2).LE.25.0) THEN
                  C=0.35+0.0016*LOC(I,2)
              ELSE
                  C=0.39
              ENDIF
              IF(LOC(I,2).GT.100.0) THEN
                  ALFA=0.0
              ELSE
                  ALFA=0.0011*EXP(-0.000015*LOC(I,2)**2.966)+
                       (0.0001/(LOC(I,2)+1.0))
              ENDIF
              C1=0.0
              ARG1=-ALFA*SYZ*SYZ
              IF(ARG1.GT.-70) C1=C*EXP(ARG1)
              C2=0.0
              ARG2=-0.00092*SQRT(SYZ**3.0)
              IF(ARG2.GT.-70.0) C2=0.43*EXP(ARG2)
              C3=0.0
              ARG3=-0.0034*SYZ
              IF(ARG3.GT.-70.0) C3=0.19*EXP(ARG3)
              CORR=(1.0-C1-C2-C3)*EXP(LOC(I,2)**2.0/(2.0*SYZ*SYZ))
              EFF=XQ(I)*0.25*CORR*100000.0
              THY=XQ(I)*920.0*1000.0
              GS=XQ(I)*143.0/24.0*1000.0*0.03*1000.0
              WRITE(LF,1035) I,(LOC(I,J),J=1,3),XQ(I),SIGY(I),AZB(I),
     *                       EFF,THY,GS
1035          FORMAT(1X,I3,F8.1,F7.1,F6.1,3X,1PE9.3,0P2F8.2,
     *               3F9.3)
          ENDIF
C          WRITE(LF,1040,ERR=900) I,(LOC(I,J),J=1,3),XQ(I),SIGY(I),AZB(I)
C 1040     FORMAT(1X,I4,3F8.1,3X,1PE9.3,0P2F8.2)
 100  CONTINUE
      GOTO 999
C
 900  ERROR=.TRUE.
C
```

```
115  999  CLOSE(LF)
116       RETURN
117       END
```

SAMPLE INPUT FILES

cnsts.dat

```
 1  PI              3.1415927
 2  RHO          1276.0
 3  CP              1.005
 4  ALPHA           0.35
 5  G               9.8
 6  K1              0.35
 7  BETA            4.7
 8  AU0          1100.0
```

site.dat

```
 1  LAT            44.33
 2  LON            81.58
 3  SRCHGT         20.0
 4  Z0              0.40
 5  ZM             30.0
```

met.dat

```
 1  YEAR         1986
 2  MONTH          10
 3  DAY            27
 4  TIME(GMT)    1324
 5  CLOUD           0
 6  U               2.8
 7  WD            300.0
 8  TA            283.2
 9  SIGT            0.00
10  STB             1
11  LRAIN           F
12  RAIN            0.00
13  LSNOW           F
14  START        1000
15  STOP         9000
16  STEP         1000
17  Z               0
18  DWN,CRS,Z  10000      0      0
19             2200       0      0
20             3500       0      0
```

SAMPLE OUTPUT FILE

needm.dat

```
 1
 2  Constants File
 3  PI          3.1415927
 4  RHO      1276.0000000
 5  CP          1.0050000
 6  ALPHA       0.3500000
 7  G           9.8000002
 8  K1          0.3500000
 9  BETA        4.6999998
10  AU0      1100.0000000
11
12
13  Site Data
14  LAT        44.33
15  LON        81.58
16  SRCHGT     20.00
17  Z0          0.40
18  ZM         30.00
19  TRISE      12.54
20  TSET       22.34
21  TNOON      17.44
22
23
24  Met Data
25  YEAR     1986
26  MONTH      10
27  DAY        27
28  JDAY      300
29  TIME     1324
30  CLDM       0
31  U          2.80
32  WD       300.00
33  TA       283.20
34  SIGT       0.00
35  STB        3
36  LRAIN      F
37  RAIN       0.00
38  LSNOW      F
39
40
41  Results
42  US          0.26
43  HF         21.77
44  ML        -90.71
45
46          DWN     CRS     Z        XQ        SY       ZB       EFF      THY     GS
47    1   1000.0     0.0   0.0  7.365E-06   104.88   118.56     0.139    6.776   1.316
48    2   2000.0     0.0   0.0  1.483E-06   200.83   280.14     0.034    1.364   0.265
49    3   3000.0     0.0   0.0  5.429E-07   289.43   505.04     0.013    0.499   0.097
50    4   4000.0     0.0   0.0  2.609E-07   371.87   792.14     0.006    0.240   0.047
51    5   5000.0     0.0   0.0  1.466E-07   449.07  1140.43     0.004    0.135   0.026
52    6   6000.0     0.0   0.0  9.130E-08   521.78  1549.14     0.002    0.084   0.016
53    7   7000.0     0.0   0.0  6.109E-08   590.56  2017.62     0.002    0.056   0.011
54    8   8000.0     0.0   0.0  4.311E-08   655.91  2545.38     0.001    0.040   0.008
55    9   9000.0     0.0   0.0  3.170E-08   718.22  3131.97     0.001    0.029   0.006
56   10  10000.0     0.0   0.0  2.408E-08   777.82  3777.05     0.001    0.022   0.004
57   11   2200.0     0.0   0.0  1.175E-06   219.10   320.09     0.027    1.081   0.210
58   12   3500.0     0.0   0.0  3.672E-07   331.36   640.88     0.009    0.338   0.066
```

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